



Brain vs. Pulmonary Blast Injury Tolerance and the Effect of Ballistic Protective Vests

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Effects of Blast on the Brain?

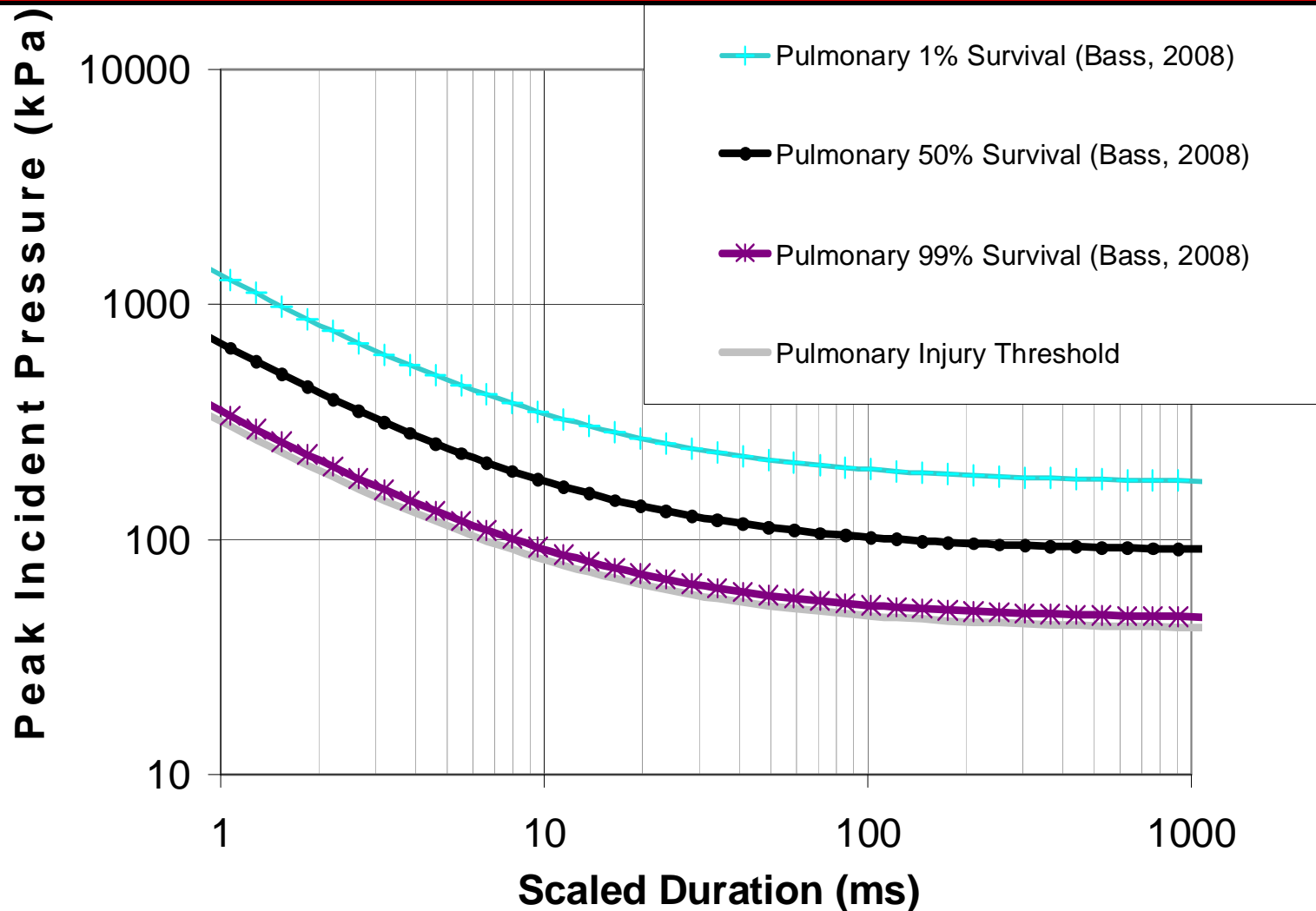


- Evidence of Blast Injury Old (Pare, 1500's)
- By late 1800's -> High Explosives -> Primary Blast Deaths
 - E.g. Rusca, 1915
 - Brain or pulmonary/gut?
- WWI
 - Trench warfare
 - Exploding shells overhead
 - French ->
 - Organic Neurotrauma caused by blast*
 - British ->
 - Buck up, get back in the trench (e.g. Mott-1916)*

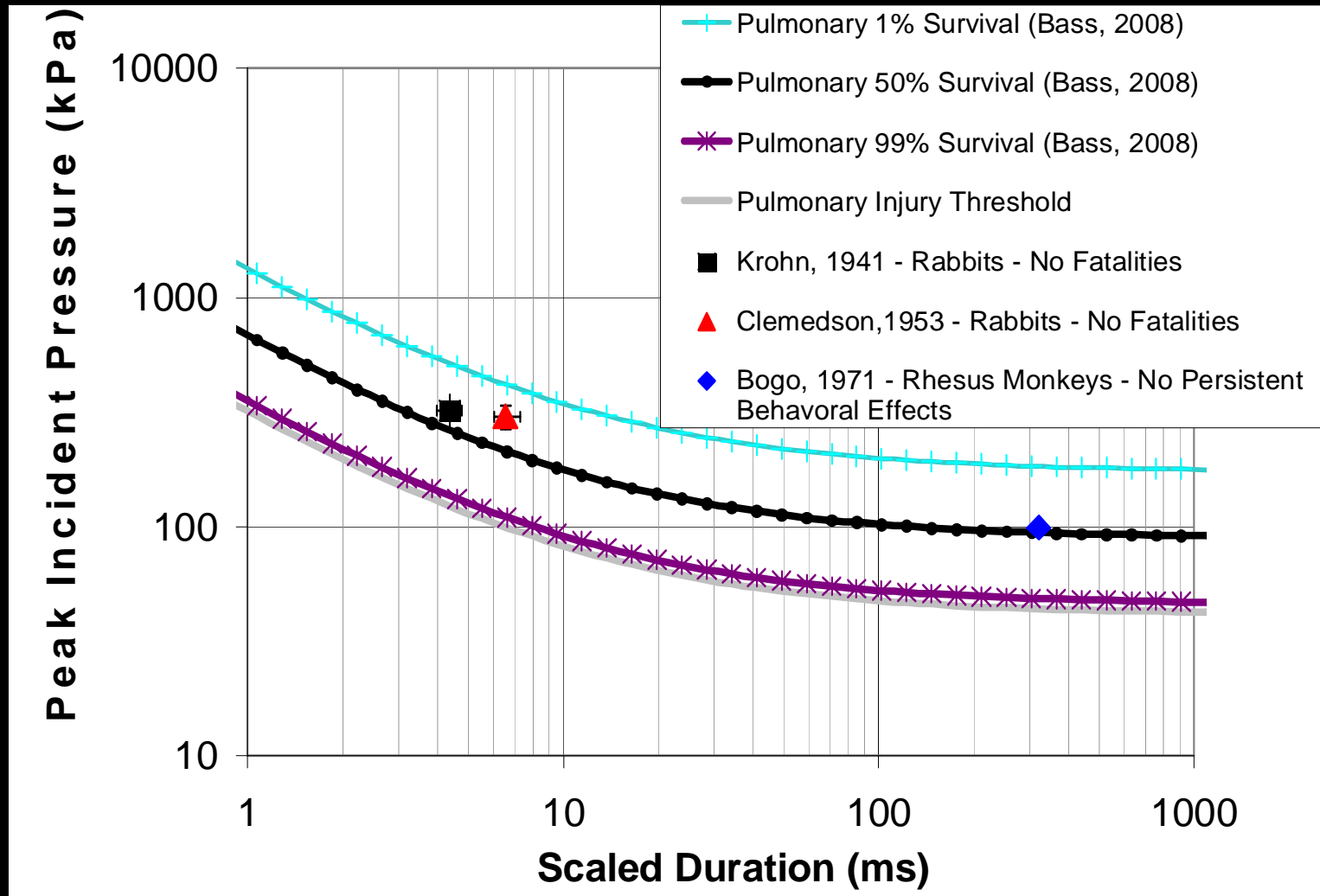
Brain Fatalities?

- Post WWI ...
- *Tolerance for Primary Blast Brain Fatalities Much Greater than for Pulmonary Fatalities*
 - Hooker-1924, Zuckerman-1942, Clemenson-1949, Richmond-1962, Bogo-1971, and implied by many others ...
- Air Containing Organs
 - Lungs, intestines, ears
- Pulmonary Injury Criteria
 - Lovelace (Bowen-1968), MRMC (Dodd-1990, Stuhmiller-1996), Bass-2008, etc.
- No Primary Blast Brain Survival/Lethality Criteria!

Blast Lung /Survival Injury Tolerance (Bass *et al*, *J Trauma*, 2008)



Previous Studies Head Injury Risk (Blast - Protected Thorax - Not Rodents)



Primary Blast Brain Tolerance Not Established!

Goal: *Establish Brain
Injury Criterion for Short
Duration Primary Blast*

Blast Overpressure



Open Space

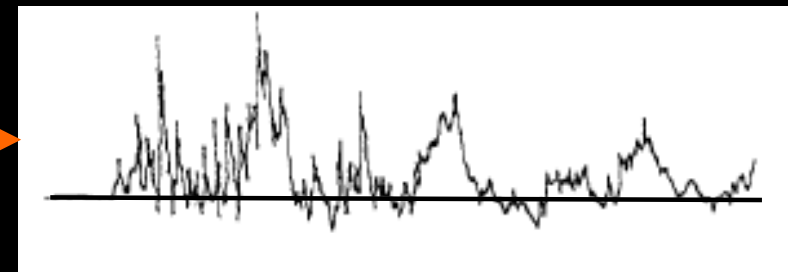


Simple or Friedlander or
“Free Field”

Pressure vs Time



Reflecting Surfaces



Complex

Pressure vs Time – Fixed Location

Blast Overpressure



Open Space

Simple → Blast

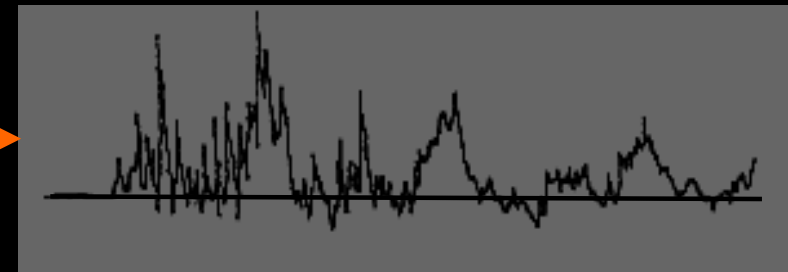
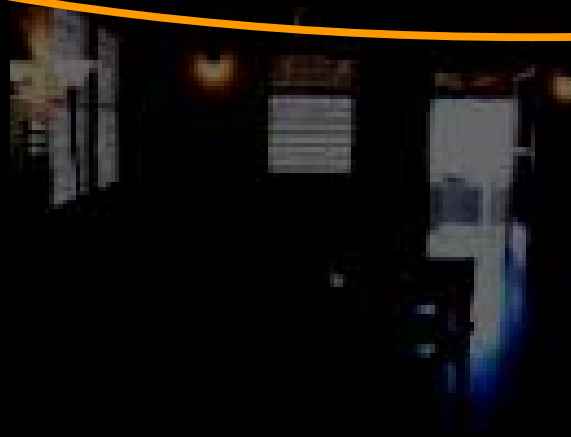


Simple or Friedlander or
“Free Field”

Pressure vs Time



Reflecting Surfaces



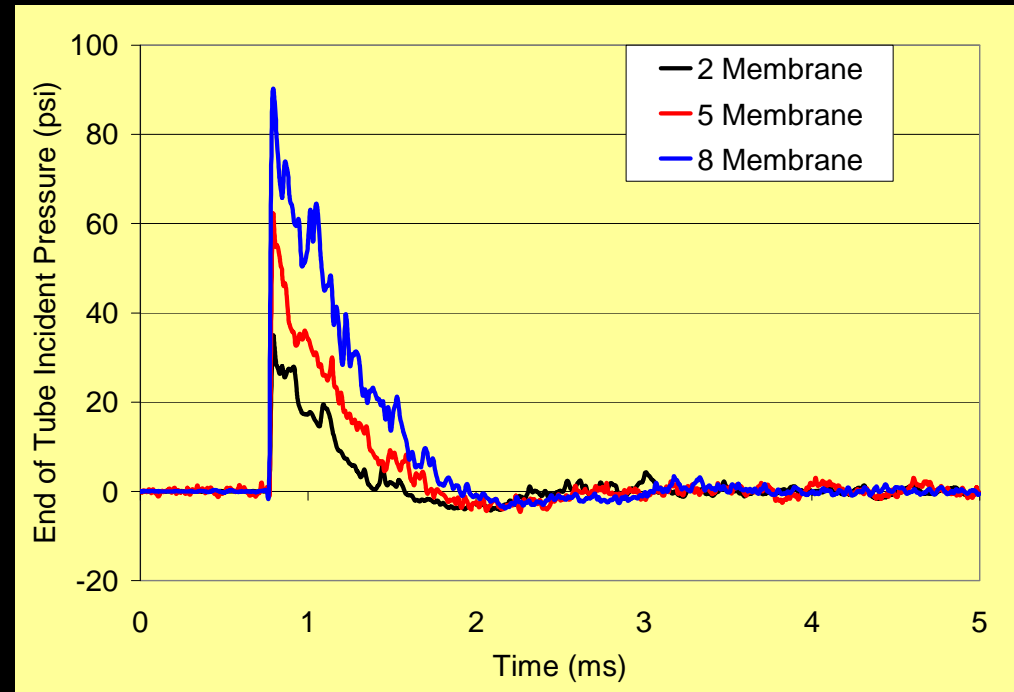
Complex

Pressure vs Time – Fixed Location

Methods

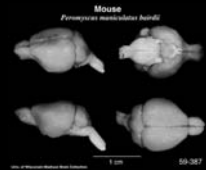
Test Setup/Shock Tube

- 8" Shock Tube, Simple Blast Incident Profile $\sim 10 \mu\text{s}$ rise
 - 1.5-3 ms duration
- Specimen -
New Zealand Rabbits
 - Match previous data
(Krohn, 1941, Clemedson, 1953)
 - Body mass ~ 4 kg
 - 12 blast specimens, 3 controls
- Head exposed, Thorax Protected by Steel Tube
 - Reduction of peak overpressure by factor of 10



Scaling (Intraspecies)

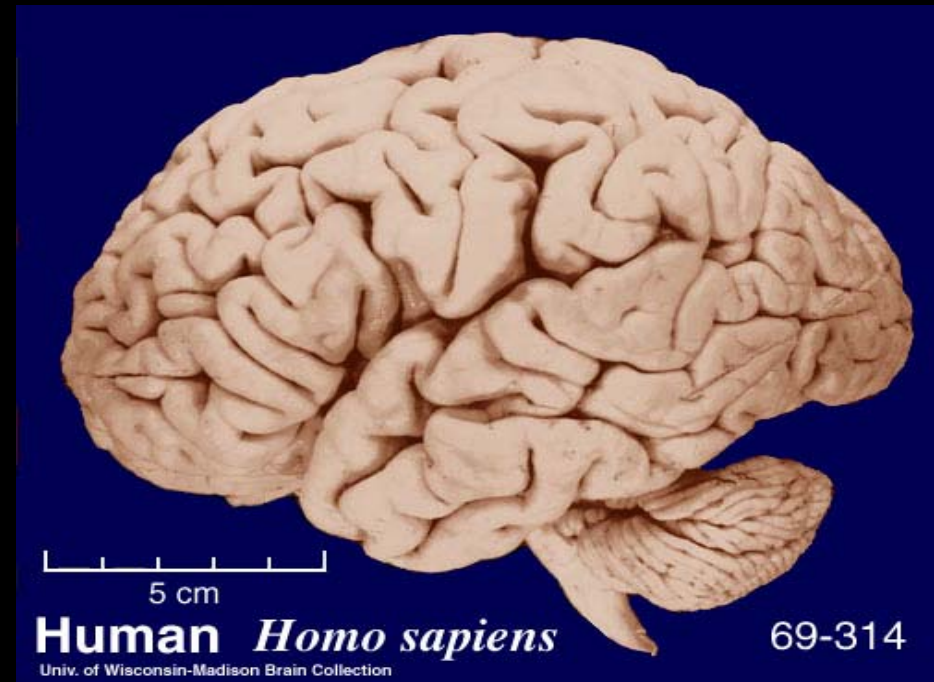
- Crucial (Rarely Verified)
- Structural/Geometric Differences Often Large (Rarely Accounted For)



Mouse Brains (4)



Rabbit Brain



Human Brain

Subject Response Scaling

Mass Ratio $\lambda = \left(\frac{M}{M_{ref}} \right)^{\frac{1}{3}}$

Velocity $V_s = V_i$

Length $L_s = \lambda \times L_i$

Acceleration $A_s = \frac{A_i}{\lambda}$

Force $F_s = \lambda^2 \times F_i$

Time $T_s = \lambda \times T_i^*$

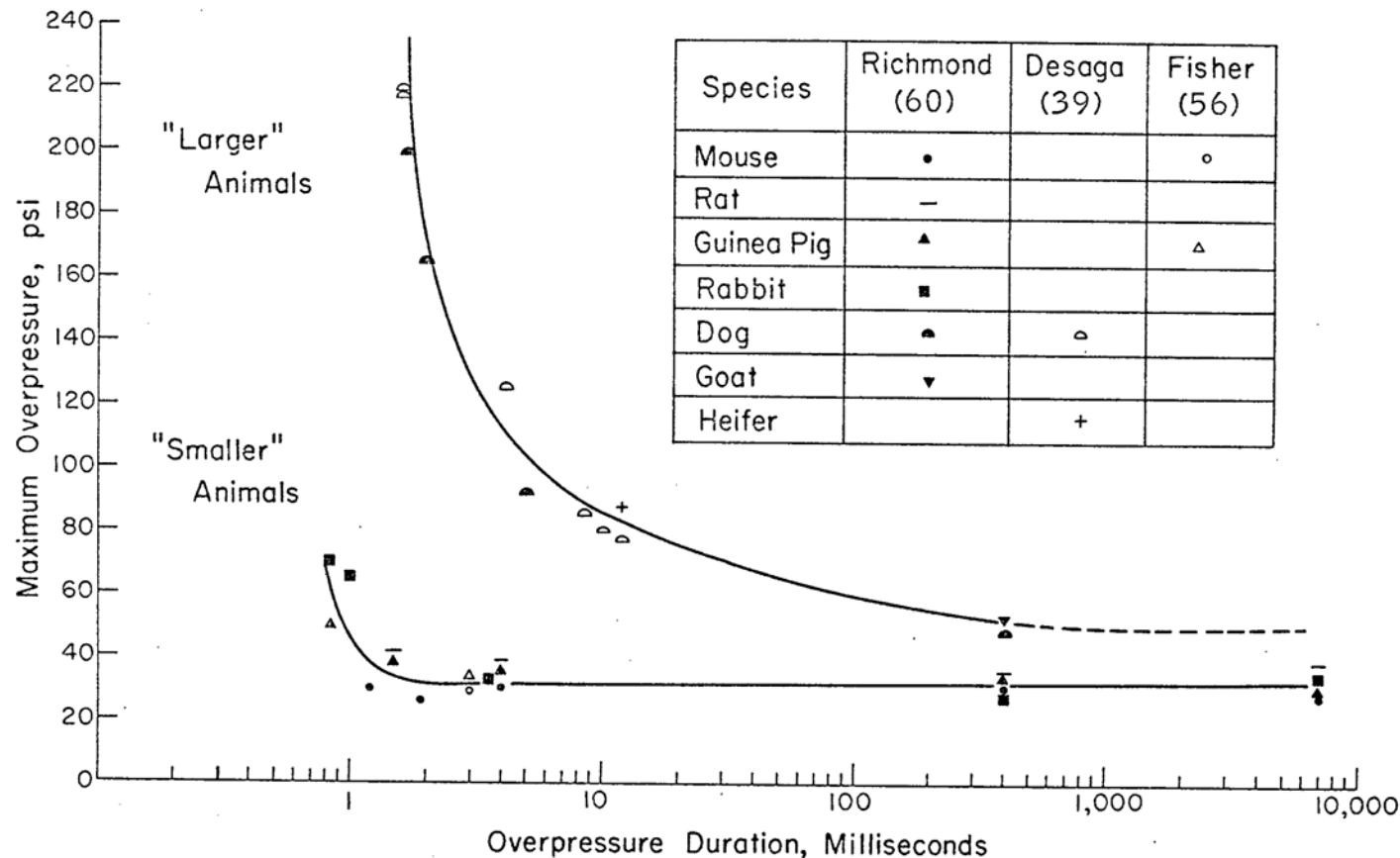
Assumptions: mass density and modulus of elasticity constant among subjects (cf. Eppinger et al, 1984)

Appropriate for Blast Brain Injury? *Don't Know*

Scaling (From Pulmonary Blast Work)



Lethality Curves for "Larger" and "Smaller" Animals



White et al,
1971

Results

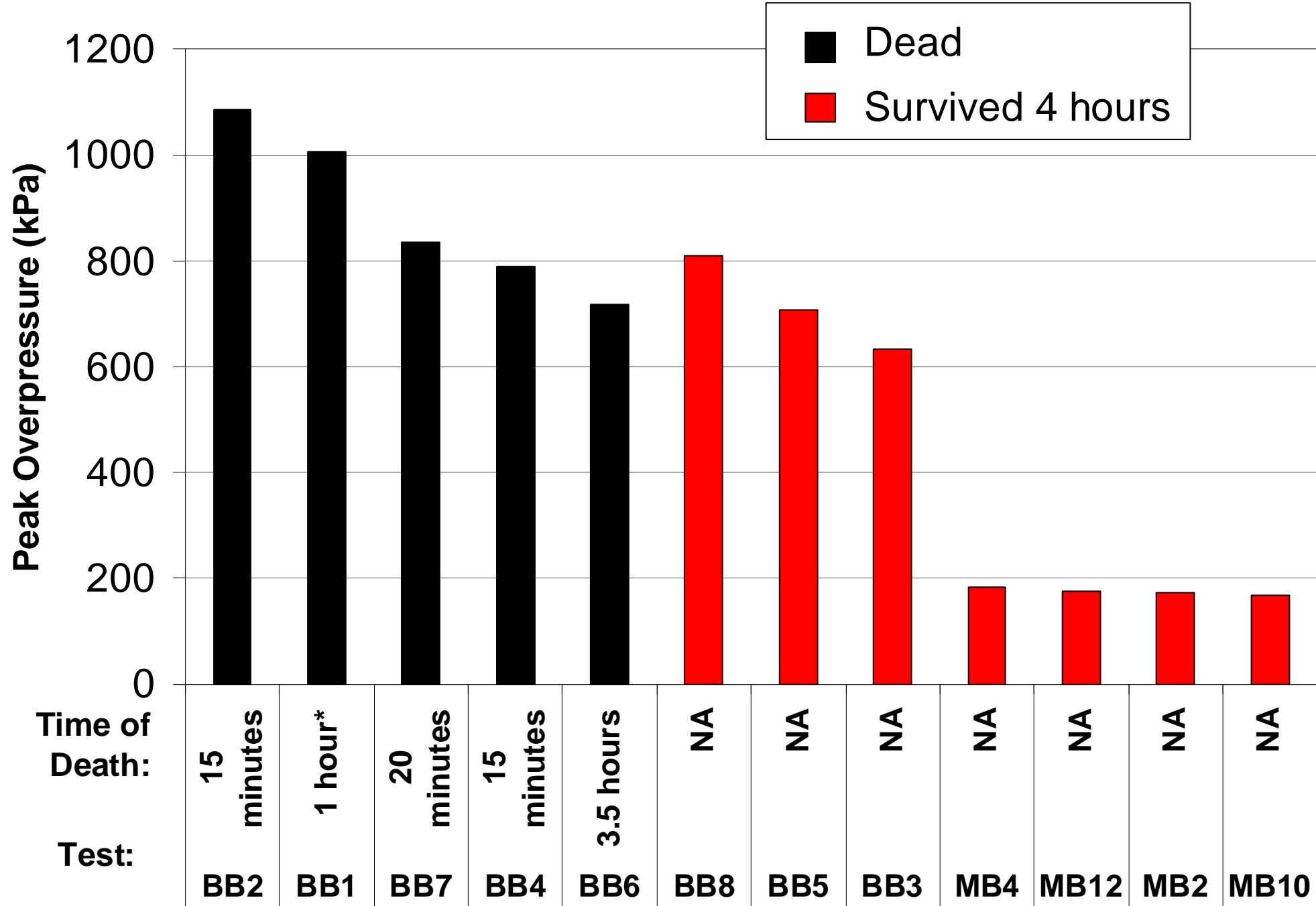
Results

■ Typical History

- Immediate Apnea (N=5 with > 600 kPa)
- Resumes breathing spontaneously < 700 kPa
- Needs ventilatory support $> \sim 700$ kPa
- Death associated with subdural bleeding
- No serious GI, pulmonary injuries

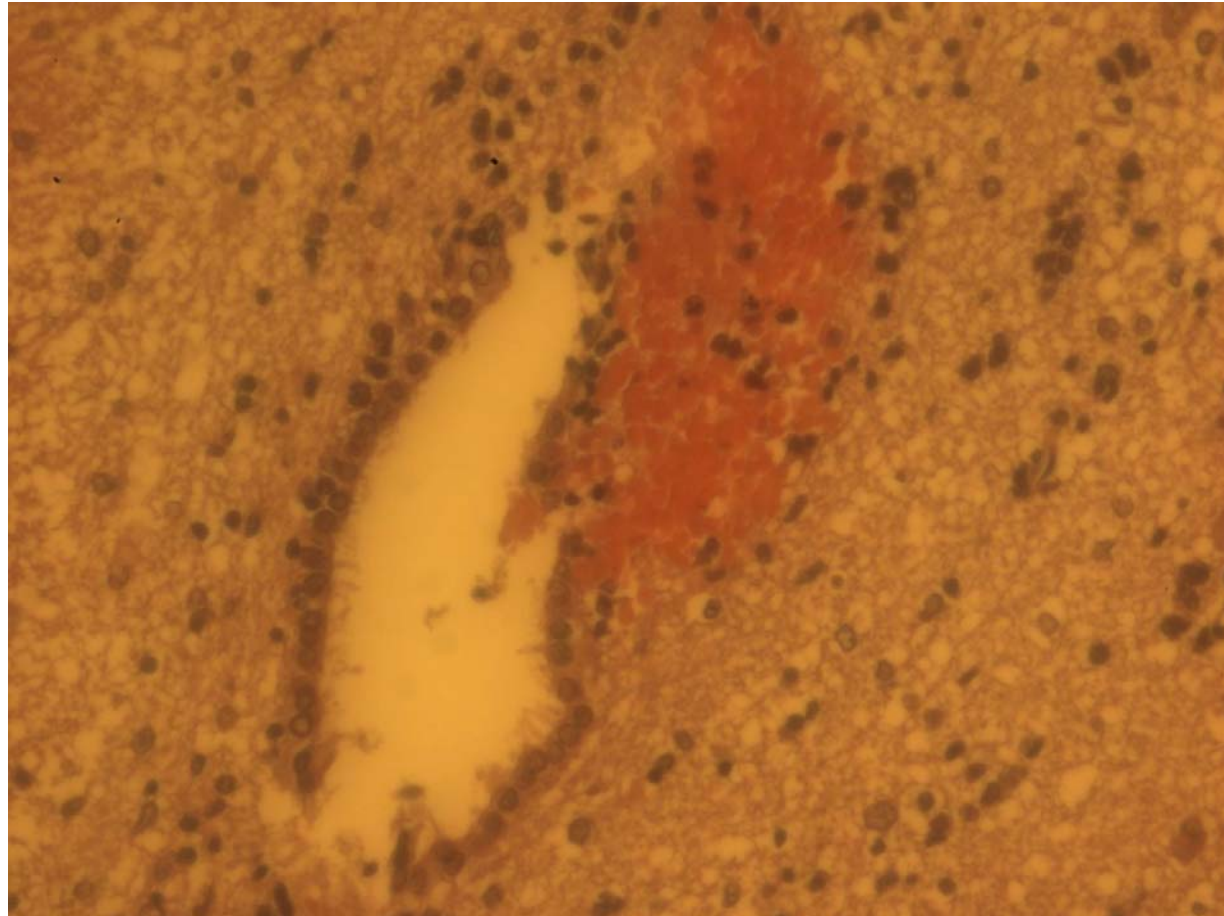
■ Current Dataset

- 12 blast specimens, 3 controls
- Highest nonfatal – 810 kPa
- Lowest fatal – 729 kPa



Typical Brain Bleeding

- Lateral Ventricle – Coronal Section

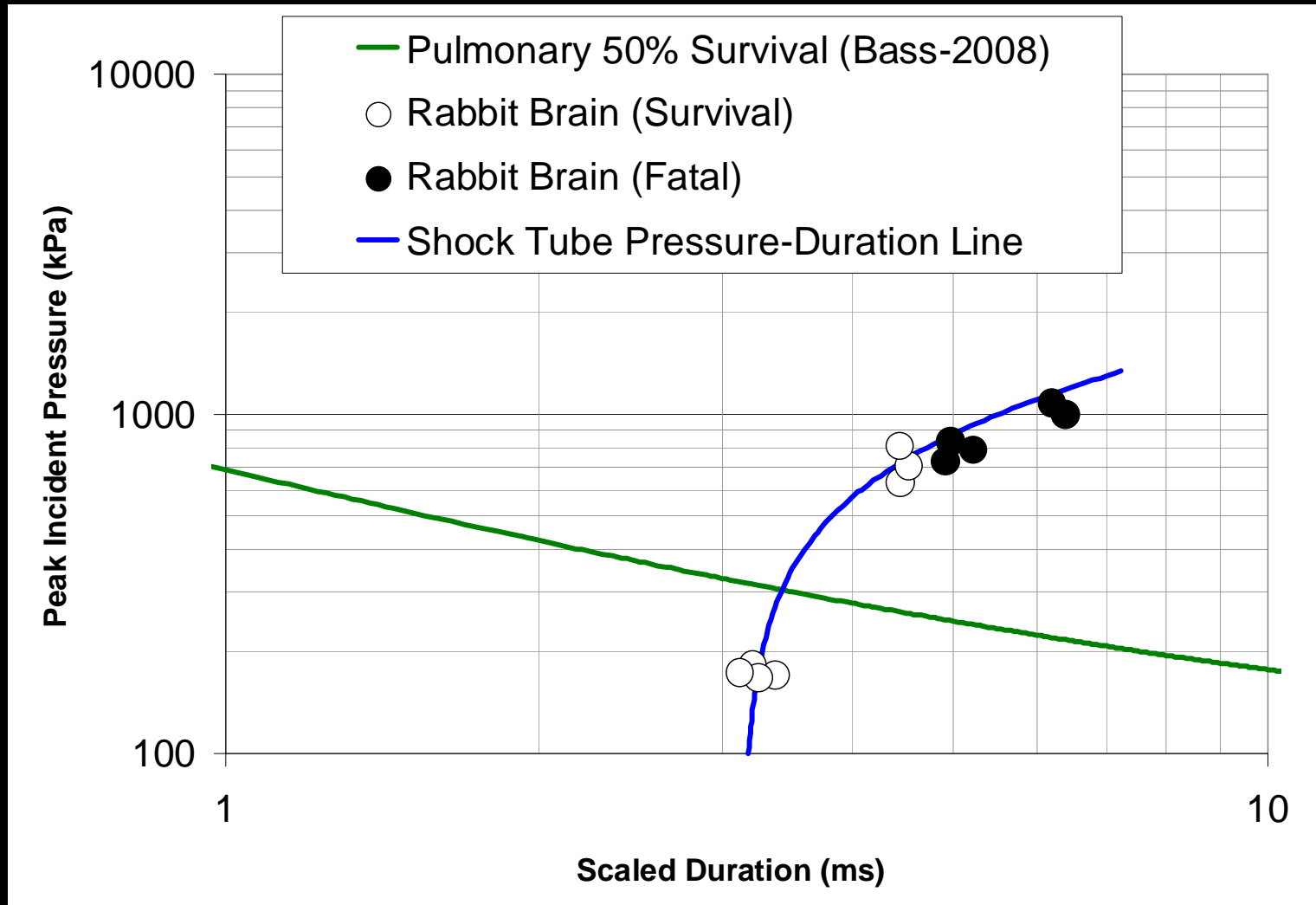


Fatal Blast Case (40X)

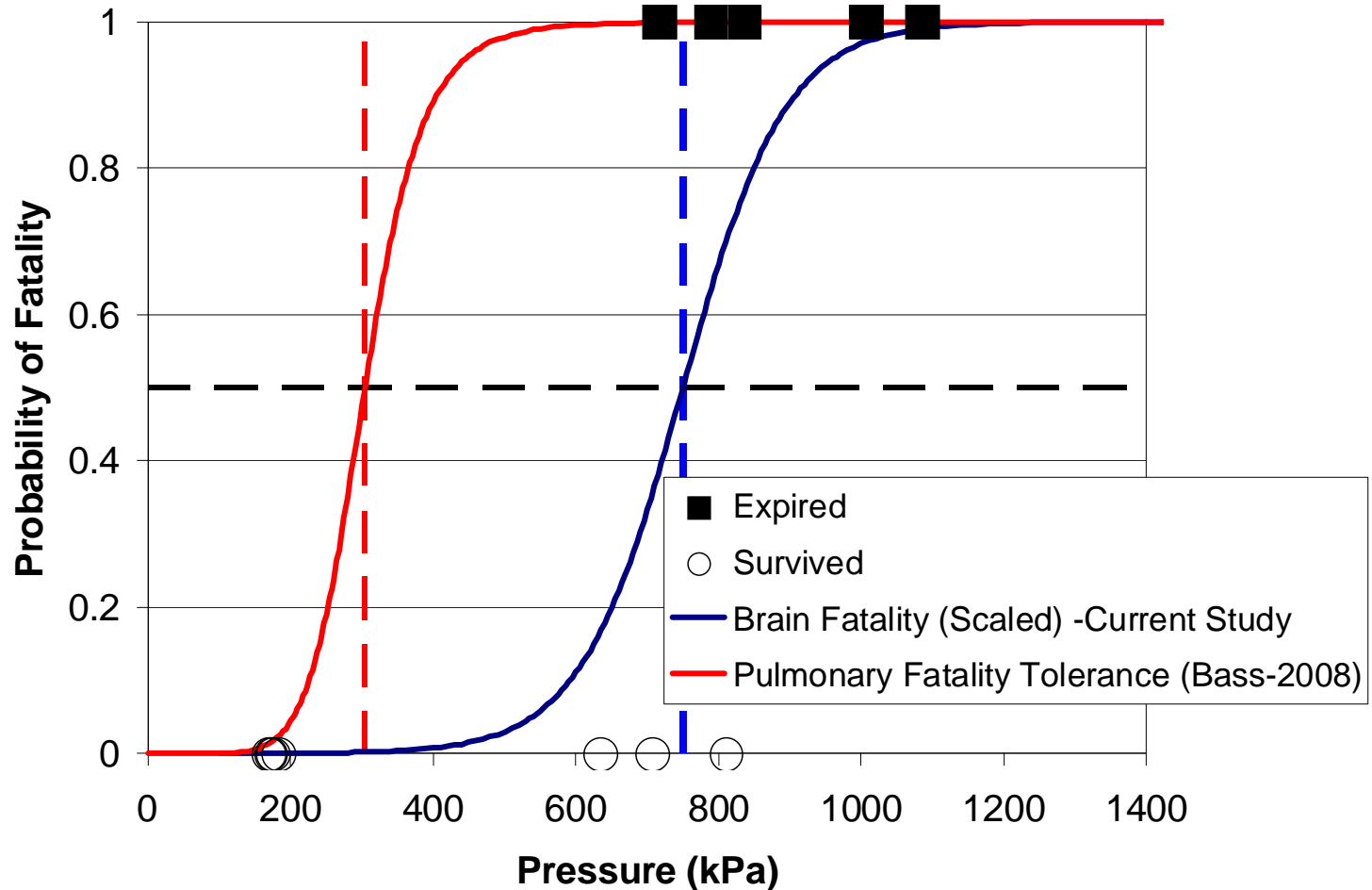
Primary Brain vs. Pulmonary



DUKE
BME



Primary Brain vs. Pulmonary



Extension in Pressure/Duration Range



■ Results

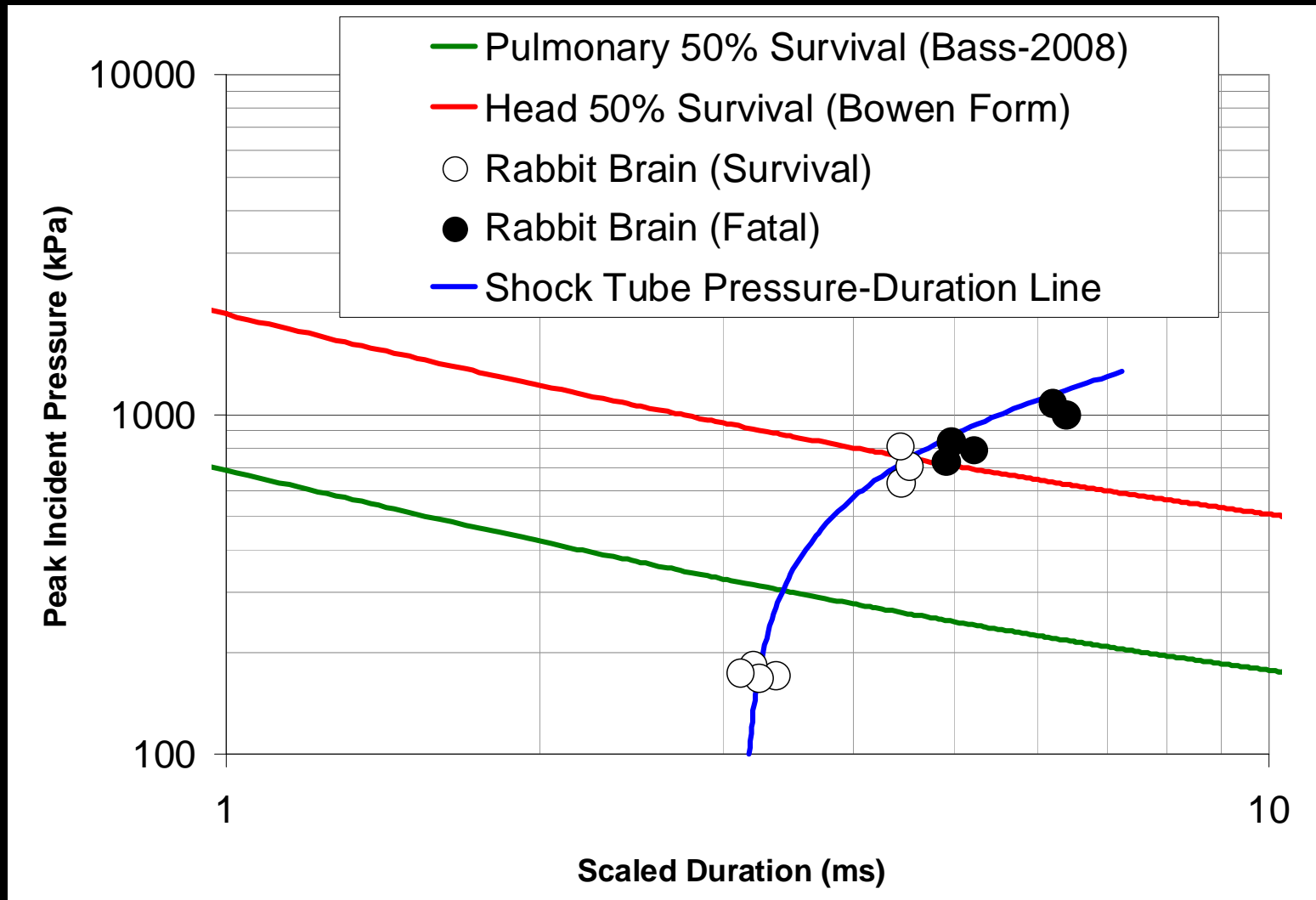
- Generally only valid along shock tube line

■ Bowen Form for Pressure/Duration

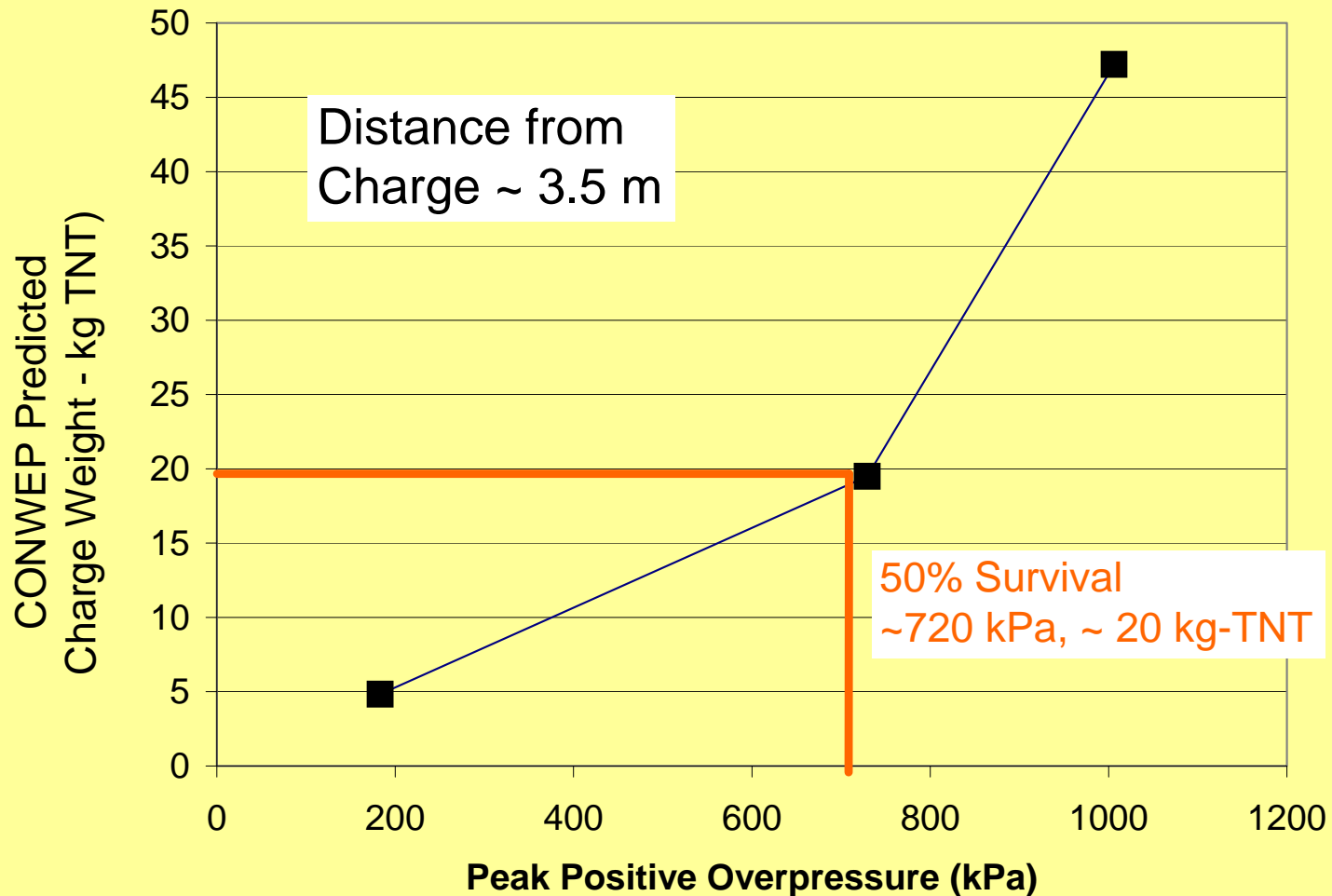
(Bowen, 1968, Bass, 2008)

- $P = P^* (1 + a \Delta T^{-b})$
- Parallel to pulmonary results of Bass (2008)

Estimates Using Bowen Form



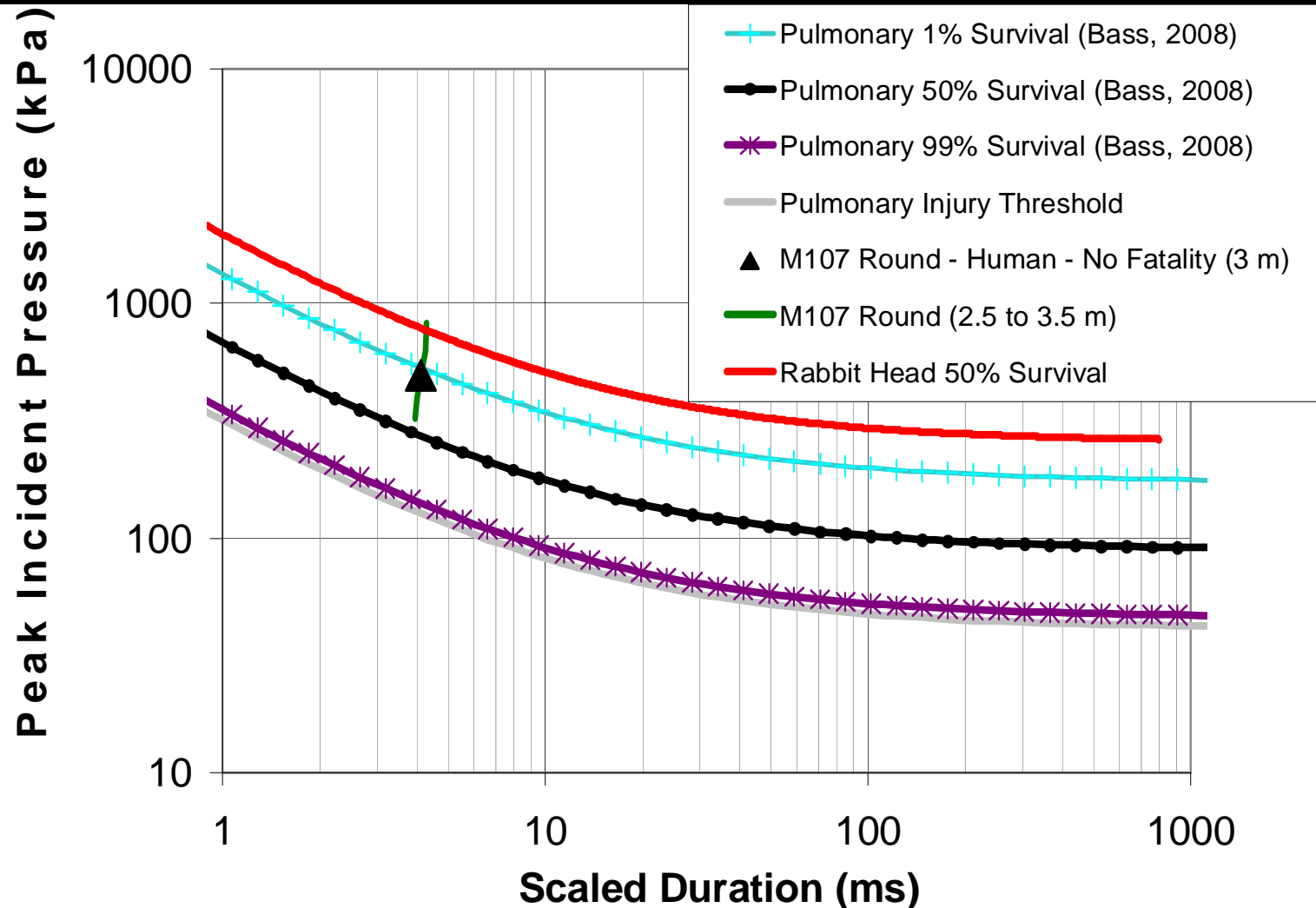
CONWEP Predictions with TNT



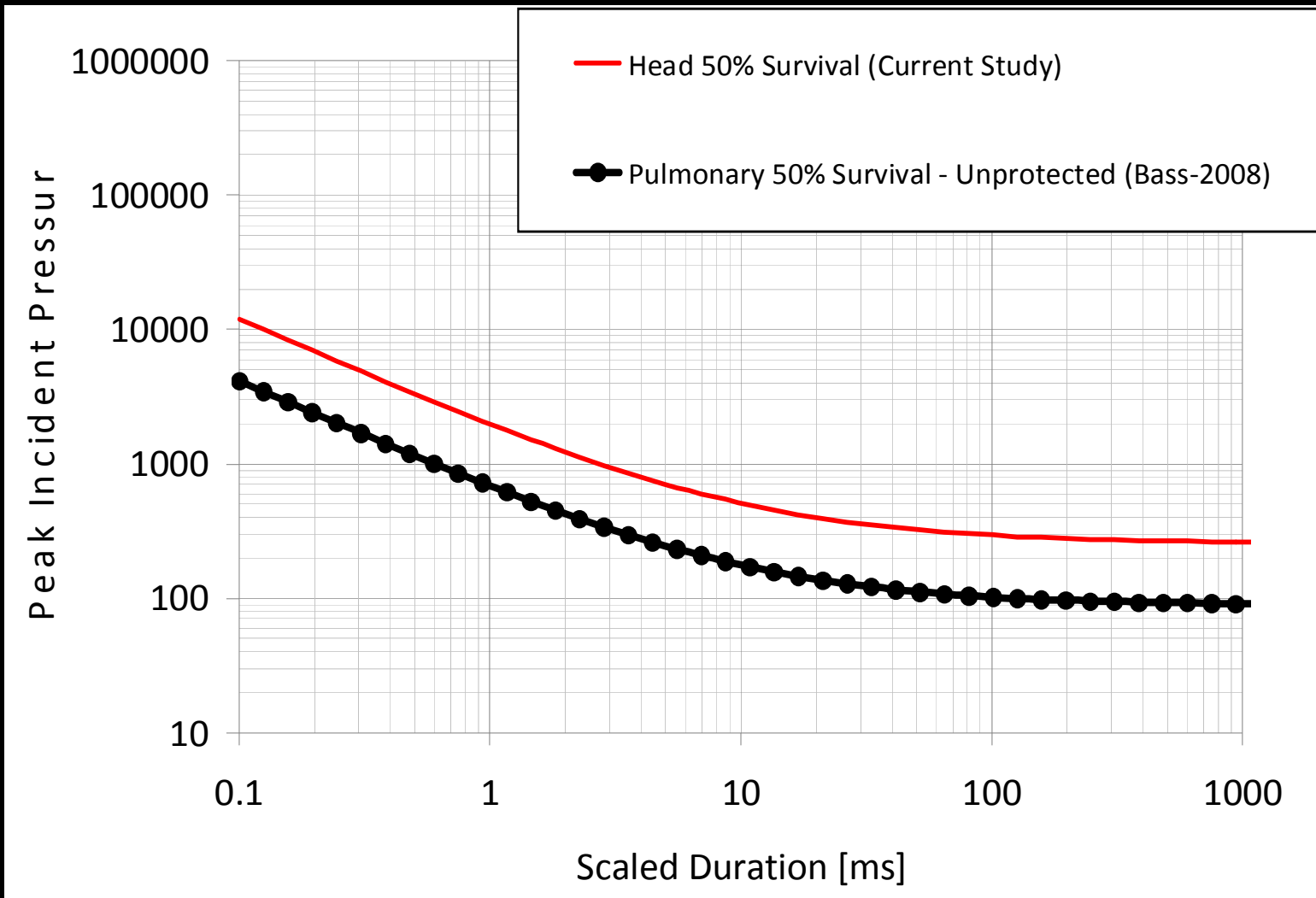
Discussion

- Anecdotal Injuries from Theater
 - Mild/moderate
 - Fatalities associated with blunt trauma, fragmentation
- How is this Study Useful?
 - Range fatalities to mild/moderate
- Why no fatalities?
 - Effect of body armor

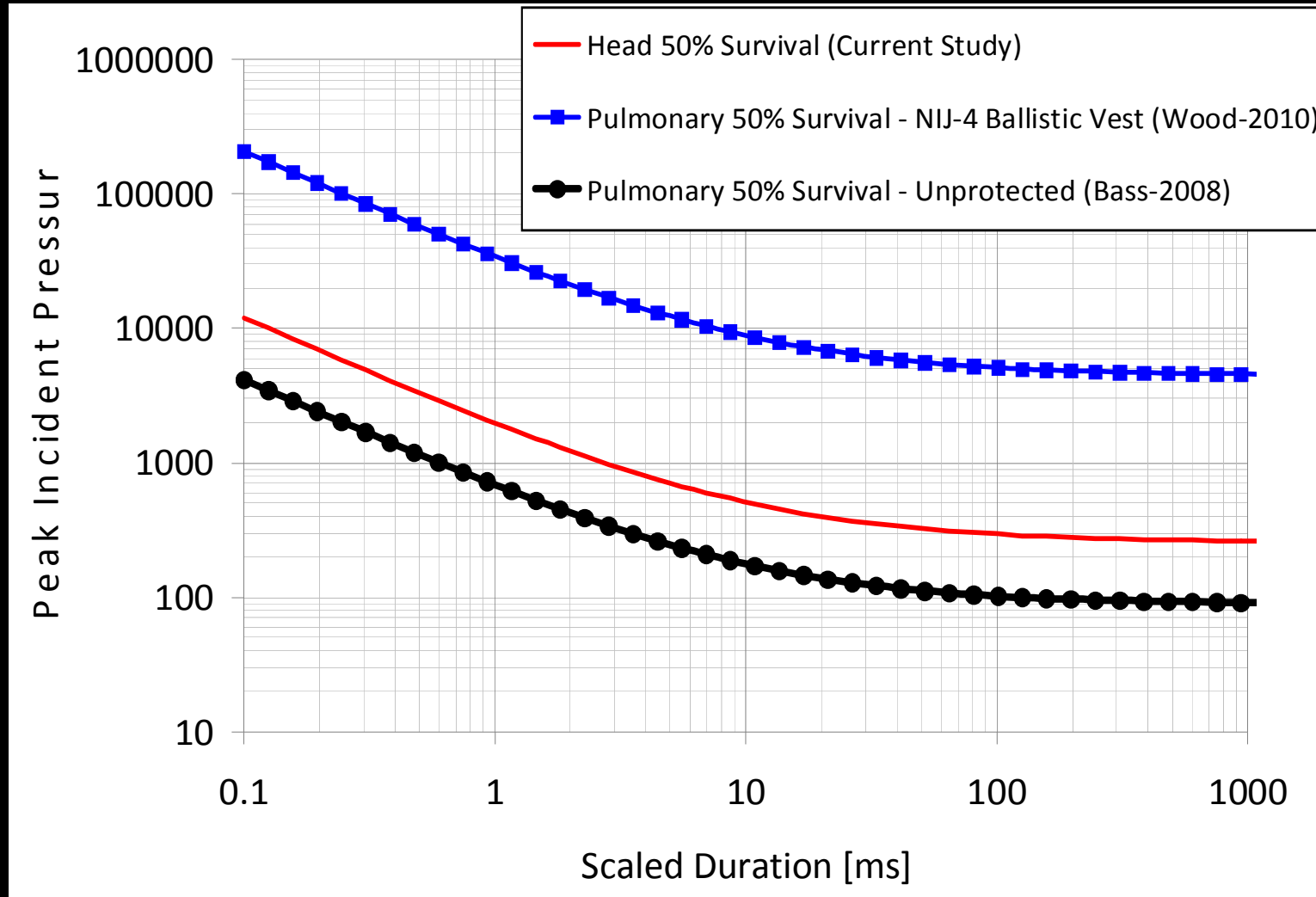
Epidemiology / Range



Effect of Body Armor



Effect of Body Armor



Conclusions

Conclusions

- *Blast Brain Fatality >> Blast Pulmonary Fatality*
 - Evidence of damage at lower than fatal levels
 - Primary blast brain 50% fatality, close to large charges
- Scaling to Human
 - Fatalities from large momentum event, scaling used likely okay for fatality/survival tolerance
 - For mild bTBI??? Unknown.
- Hard Body Armor Increases Pulmonary Tolerance

Upcoming Work

■ Pulmonary

- Long Duration Blast (Accepted for J Trauma, 2010)
- Effect of Multiple Blast (Submitted to J Trauma)
 - Application to complex blast?

■ Brain

- This study (Submitted to J Neurotrauma, 2010)
- Larger study (Manuscript in preparation)
 - Other mild/moderate injury criteria

■ Effects of Blast Behind Body Armor

- Accepted for Personal Armor Systems Symposium (Sept, 2010)

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